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TREATMENT EFFICIENCY OF PIGGERY WASTEWATER BY SURFACE AND HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLANDS

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Abstract. Constructed wetlands (CWs) have been used to treat various types of wastewaters such as urban runoff, acid mine drainage, municipal, industrial, and livestock wastewaters. This study was conducted to evaluate the effectiveness of two constructed wetlands (surface and horizontal subsurface flows) for piggery wastewater treatment after biogas process. The wetland plant *Phragmites australis* Cav. was used in two CWs. The flow rate of the CWs was 100 liters/day with the hydraulic retention time (HRT) of 3 days. Parameters including pH, chemical oxygen demand (COD), total suspended solids (TSS), NH_4^+-N, total nitrogen (TN) and total phosphorus (TP) were measured. After 45 days experiments, the results showed that the horizontal subsurface flow CWs had better treatment performance compared to the surface flow system. The pH of the wastewater after CWs treatment was in the range of 6.7 to 7.3. The removal efficiency of TP, TSS, COD, TN and NH_4^+-N by surface flow CWs was 80, 60, 66, 60 and 65 %, respectively while those by horizontal subsurface flow system was 86, 78, 74.6, 67.1 and 74.2 %, respectively. The water quality of the effluents of both two CWs met the Vietnamese standards for livestock wastewater (QCVN62-MT:2016/BTNMT, column B).

Keywords: surface flow CW, horizontal subsurface flow CW, *Phragmites australis*, piggery wastewater, removal efficiency.

Classification numbers: 3.3.1, 3.3.2, 3.4.2.

1. INTRODUCTION

Pig farming is of great importance in Viet Nam. However, swine wastewater has high concentration of biological oxygen demand (BOD), chemical oxygen demand, total suspended solids, high nutrients (C, N, and P) and strong odors [1]. Swine wastewater treatment can be a difficult issue due to problems related to investment, running cost and treatment efficiency. Wastewater treatment must be done in a reliable and sustainable manner to avoid significant environmental impacts (for ground waters, surface water and surrounding environment).

There have been many studies and applications of constructed wetlands (CWs) in piggery wastewater treatment. The CWs are considered as an eco-friendly, cost-effective technology with a minimum negative impact on the environment [2]. Some researchers reported the potential of plant species such as bulrush (*Scirpus* spp.), cattail (*Typha angustifolia* L.), and vetiver grass (*Vetiveria zizanioides* L.) for piggery wastewater treatment [3]. Among wetland plants, *Phragmites australis* has been widely used in CWs [4] and this species had an appropriate efficiency in the treatment of municipal wastewater [5 - 7], domestic wastewaters [8] and swine wastewater [9, 10]. In a prior study evaluating chemical oxygen demand (COD) removal efficiency from swine wastewater by free water surface flow constructed wetland (FWS CW), it has showed that plants and microorganisms have important role in this process [11]. Another investigation demonstrated that subsurface flow constructed wetland is also suitable technology for treating swine wastewater under the local conditions of Yucatas, Mexico [12]. According to Sezerino *et al*. [13] horizontal subsurface flow constructed wetland (HSF CW) proved to be very suitable for nutrient treatment from piggery wastewater. Contaminants in this process were removed by various mechanisms such as sedimentation, filtration, microbial degradation and plant uptake.

Selection of CW types for wastewater treatment depends on the loading rates, wastewater types and environmental conditions. In previous studies, some researchers compared surface-flow with subsurface-flow cells [14, 15]. Researches on the comparisons of both systems (FWS CW and HSF CW) regards to piggery wastewater treatment after biogas process, using similar loading rate and special ratio between the length and width of the CWs' tank have been limited.

The objective of this study is to evaluate the treatment efficiency of piggery wastewater after biogas technology by FWS CW (using the submerged and emergent plant) and horizontal subsurface flow constructed wetland in a greenhouse scale experiment. For this purpose, pilot CWs (FWS and HSF CW) were constructed and operated. The results of the study would provide useful knowledge and experience to design and construction of suitable CW for piggery wastewater treatment.

2. MATERIALS AND METHODS

2.1. Materials

Table 1. Characteristics of the wastewater influent after biogas technology.

Parameter	Unit	The number of samples	Influent (Avg. ± Stdev)	Vietnamese standard[a]
pH	-	15	5.37 ± 0.11	5.5 – 9
TSS	mg/l	15	208.01 ± 6.61	150 mg/l
NH_4-N	mg/l	15	45.30 ± 3.13	-
TN	mg/l	15	188.02 ± 8.92	150 mg/l
COD	mg/l	15	800.70 ± 14.60	300 mg/l
TP	mg/l	15	33.77 ± 1.82	-

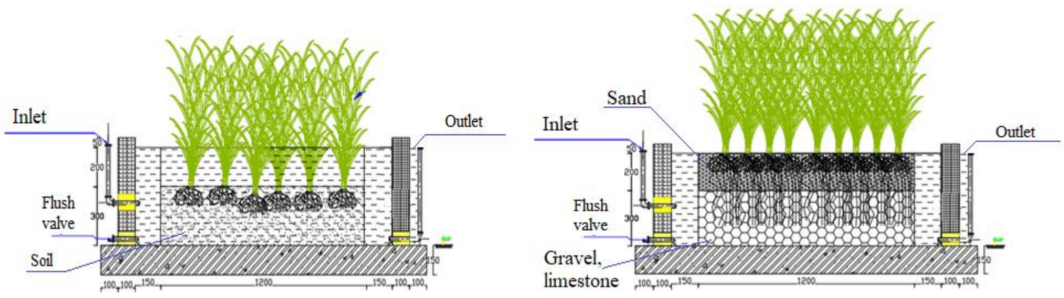
Avg. ± Stdev.: Average ± Standard deviation.
–: Undefined.
a: Vietnam’s technical regulation for livestock wastewater discharge quality (QCVN62-MT:2016/BTNMT, column B).

Phragmites australis (Cav.) was collected on the Red River bank in Ha Noi and was grown in two constructed tanks filled with soil (FWS CW) and gravel/limestone/sand (HSF CW) during 90 days by tap water and fertilized in a certain time. Plant density was 15 cm × 15 cm. When the plant shoots reached 30 cm, the experiment was started. Wastewater was collected at the pig farm at Tot Dong commune, Chuong My district, Ha Noi, Viet Nam. The standards for livestock wastewater discharge of Viet Nam and initial concentrations of the wastewater were shown in Table 1.

2.2. Experimental design

The design of FWS CW was as follows: length (L) × width (W) × height (H) = 1500 × 500 × 500 (mm). Natural soil was used as a substrate and *Phragmites australis* (Cav.) grown on the soil (Fig. 1b).

The design of HSF CW was as follows: L × W × H = 1500 × 500 × 500 (mm). The HSF CW was designed using limestone (2-4 cm grain size; 15 cm height), gravel (0.5 - 1 cm grain size; 15 cm height) and sand (20 cm height) as a substrate and *Phragmites australis* (Cav.) grown on filter media (Fig. 1a). Additional length of 150 mm was constructed in both input and output of surface and horizontal subsurface flow systems for evenly and constantly allocating water (Fig. 1.a, b).



(a) (b)

Figure 1. Surface flow constructed wetland (a) and Horizontal subsurface flow constructed wetland (b).

The experiment was conducted in 45 days with wastewater flow of 100 liters per day for each system, corresponding to N and COD mass loading rates of 18.8 g N/day and 80.07 g COD/day, with the hydraulic retention time (HRT) of 3 days. Input and output wastewater samples of surface and horizontal subsurface constructed wetland systems were collected every 3 days, total 15 times of taking samples with three replicates for each CW. The methods for measurement were shown in Table 2.

Table 2. The methods used for measurement of swine wastewater parameters.

No.	Parameters	Unit	Analytical methods
1	pH	-	TCVN 6492 : 2011
2	COD	mg/l	SMEWW 5220C : 2012
3	TSS	mg/l	TCVN 6625 : 2000
4	T-N	mg/l	TCVN 6624-2:2000
5	NH_4^+-N	mg/l	TCVN 6179 -1 : 1996
6	T-P	mg/l	TCVN 6202-2008

3. RESULT AND DISCUSSION

3.1. Plant growth and development

Phragmites australis (Cav.) was grown in two constructed tanks during 90 days by tap water and fertilized in a certain time. When the shoots reached 30 cm, the experiments were started. The growth of *Phragmites australis* (Cav.) in FWS CW was better than that of HSF CW (The soil is more favorable for plant growth than sand and gravel). After 45 days of operation, the shoots heights were 45.12 ± 7.13 cm in HSF CW, whereas in FWS CW, the shoots heights were 54.32 ± 9.27 cm. In both two CWs, *Phragmites australis* (Cav.) grew explosively and covered the wetland tank area.

3.2. pH values

The pH values of the water samples in the inlet was 5.37±0.13 and did not meet the permitted standards. After passing CWs, pH values of the effluents from FWS CW and HSF CW varied within 6.70 ± 0.26 and 7.3 ± 0.23, respectively (Fig. 2). The pH values were stable in the range of 6.7-7.3 during the experiment, which were favourable ranges for plant growth [16].

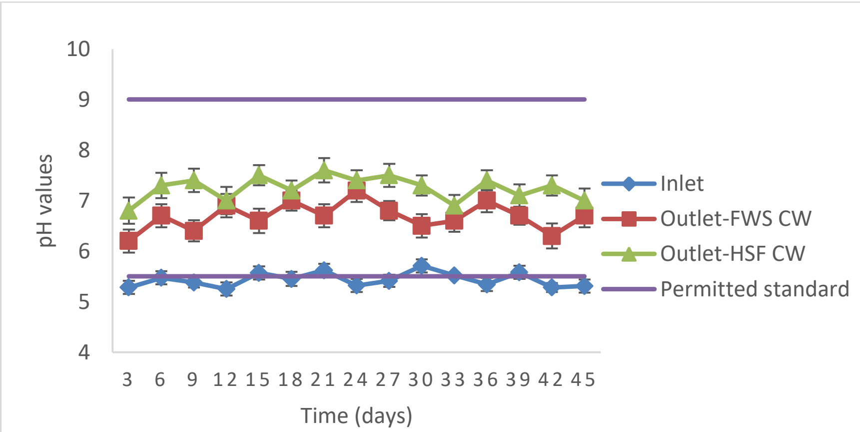


Figure 2. pH values in inlet and oulet of CWs.

The obtained experimental results showed that the pH values of HSF CW were higher than that in FWS CW due to the use of limestone composed of carbonate compounds in HSF CW. Dissolution of primary carbonate minerals in the HSF CW was important process harnessed for alkalinity generation [17]. However, the pH values of the outlet of both two investigated systems met the permitted standard (QCVN62-MT:2016/BTNMT, column B).

3.3. The removal efficiencies of COD and suspended solids

TSS concentrations in wastewater outlet of FWS CW and HSF CW systems decreased during the experimental time. The removal efficiency of TSS by FWS CW system was 60 % while that by HSF CW system reached 78 %. In previous reports, the efficiency of TSS removal was high when using subsurface constructed wetlands and reached 84.3 % [18] and 64 - 78 % [12]. The obtained results (Fig. 3) demonstrated that the removal rate of TSS in subsurface flow CW system was higher than that in surface flow CW system.

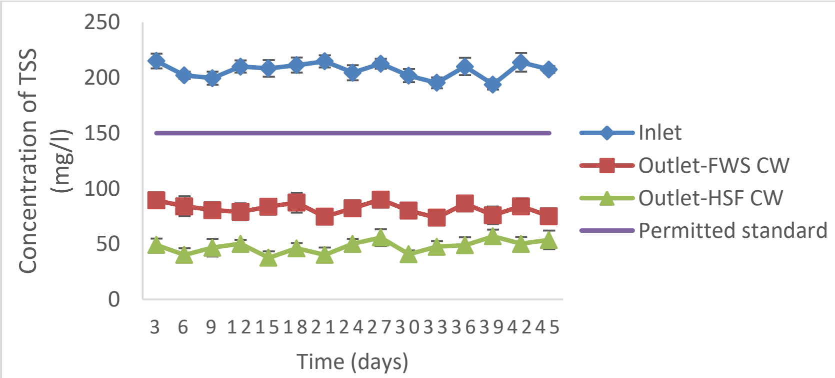


Figure 3. TSS concentrations in inlet and outlet of the constructed wetlands.

In HSF CW having filter materials and plants, suspended solids were effectively removed by filtration and settlement [19] while the FWS CW indicated less effective treatment of TSS because of no having good filter material. Concentration of TSS in outlet of FWS CW and HSF CW decreased during the experiment (Fig. 3). TSS concentration in the outlet was recorded as 83.07 mg/l for FWS CW and 45.71 mg/l for HSF CW, meeting the permitted standard (QCVN62-MT:2016/BTNMT, column B).

COD concentration in wastewater inlet was higher than the allowable permitted standard up to 2.67 times (QCVN62-MT:2016/BTNMT, column B). During 45 days of the experiment, concentration of COD decreased (Fig. 4). The removal rate of COD was 66 % in FWS CW and 74.6 % in HSF CW. The removal rates of COD in two wetlands during this study were equivalent to some previous CW studies: COD removal efficiency varied between 64 and 82 % in potato processing wastewater treatment [20], 64 % [21] and 52 - 78 % in swine wastewater [12].

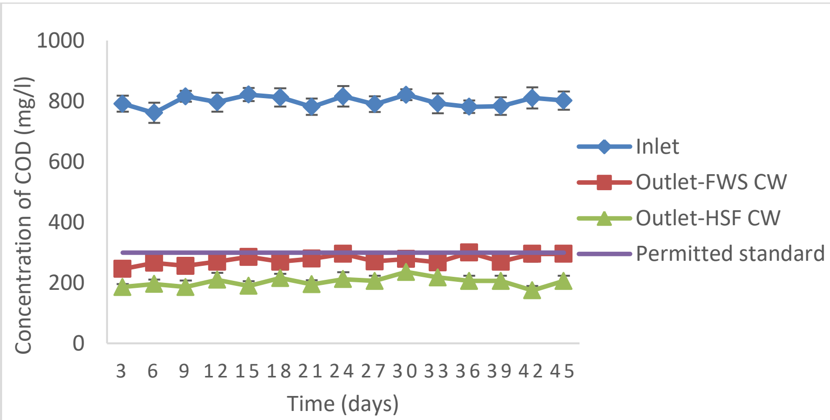
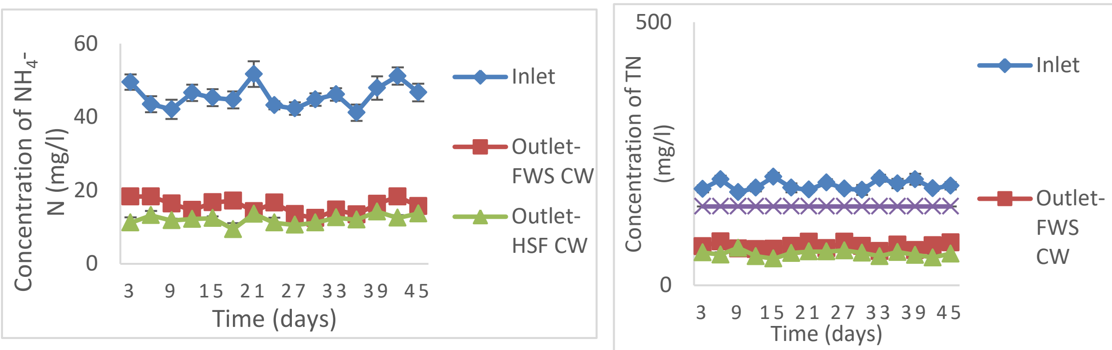


Figure 4. COD concentrations in inlet and outlet wastewater of constructed wetlands.

In HSF CW, organic compounds are degraded aerobically as well as anaerobically by bacteria attached to underground organs (i.e. roots and rhizomes) of plants and media surface, therefore COD removal is generally very high [22]. In FWS CW, the mechanism of COD removal is based only on rhizosphere organisms [19]. This difference could explain why the COD removal efficiency of HSF CW was higher than that in FWS CW in our study. The average concentrations of remained COD in the wastewater in FWS CW system was 271.91 mg/l while that value for HSF CW system was recorded as 203.42 mg/l, meeting the permitted standard (Fig. 4).

3.4. Nutrient removal

NH_4-N concentration in the outlet fluctuated around 11.68 mg/L (equivalent to 74.2% of removal rate) in HSF CW while that value in the FWS CW was 15.83 mg/L (equivalent to 65% of removal rate).



(a) (b)

Figure 5. NH_4-N (a) and TN (b) concentrations in the wastewater inlet and outlet of CWs.

The average concentration of TN in the inlet was 188 ± 8.97 mg/l, which did not meet the permitted standard (Fig. 5b). During 45 experimental days, the mean TN removal efficiency was 67.1 % and 60 % in HSF CW and FWS CW, respectively. Concentrations of TN in the outlet of both two investigated CWs met the permitted standard, type B (Fig. 5b).

The results from this study are similar to those of González *el al.* [12] and Sezerino *et al.*, [13] reporting that TN removal efficiencies in their researches reached up to 68 % and 72 %, respectively. On the other hand, other authors reported that lower TN removal efficiencies, ranging from 40 to 55 % [23] and from 30 to 40 % [24]. The relatively high removal rates obtained from this study showed that nitrogen treatment in swine wastewater by FWS CW and HSF CW is suitable. Among different TN removal mechanisms, nitrification-denitrification is generally considered to be the most important way [19] while the amount of nitrogen adsorbed by filter materials is limited [**Error! Reference source not found.**]. So it is understandable to observe that there was no big difference between two investigated systems in TN removal.

The TP removal efficiency of the two CWs reached up to 80 % for FWS CW and 86 % for HSF CW and was higher that value reported by other authors [12, 25]. By increasing hydraulic retention time to 10 days, the removal efficiency of TP can reach 85 % [26].

It has been suggested that plant uptake played a major role in the removal of nitrogen and phosphorus [27]. *Phragmites australis* (Cav.) can also uptake high concentration of nutrients [28 - 30]. The nutrient removal mechanism in FWS CW may be based on accumulation into plants biomass, after that the nitrogen and phosphorus can be removed through plant harvesting.

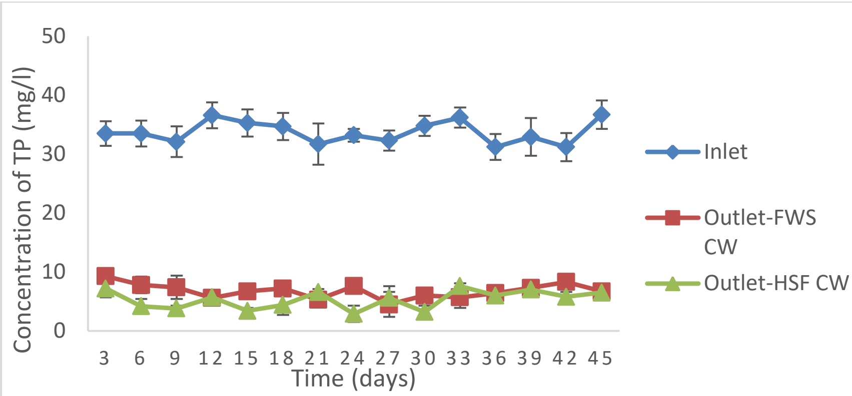


Figure 6. TP concentrations in inlet and outlet wastewater of constructed wetlands.

Apart of nutrient accumulation in plants, the filtration/sedimentation of suspended particles by filter materials in HSF CW and microbial action also play an important role [19]. Though HSF CWs have lower area demands compared to FWS CWs, but capital costs might be higher [31, 32]. This CWs type has been proved to be very effective in the treatment of municipal wastewater, removing TSS and organic matter (BOD_5) at high rates [32]. Types of wastewater, land area and investment cost are important factors when choosing suitable CW for application.

4. CONCLUSIONS

The surface flow and horizontal subsurface flow constructed wetlands showed potential for piggery wastewater treatment. The removal efficiencies of nutrients and COD reached more than 60 %. During the experiment, pH values and concentrations of COD, TSS, TN in the wastewater outlet of the two CWs have met the permitted standard for type B of livestock wastewater. In this case, the horizontal subsurface flow constructed wetland system planted with *Phragmites australis* with the use of a combination of gravel, limestone and sand showed better treatment efficiencies than surface flow constructed wetland system having only soil and *Phragmites australis*. According to the research results, HSF CW is more suitable for application on an enlarging area scale in pig farming.

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REFERENCES

1. Costa R. H. R. and Medri W. - High-rate pond for treatment of piggery wastes, Water Sci. Technol. **42** (10-11) (2000) 357-362.
2. Toscano A., Langergraber G., Consoli S., and Cirelli G. L. - Modelling pollutant removal in a pilot-scale two-stage subsurface flow constructed wetlands, Ecological Engineering **35** (2) (2009) 281-289.
3. Stefanakis A. I., Akratos C. S., and Tsihrintzis V. A. - Vertical Flow Constructed Wetlands: Ecoengineering Systems for Wastewater and Sludge Treatment (1st ed.). Amsterdam, The Netherlands: Elsevier Publishing, 2014.

4. Vymazal J. and Kröpfelová L. - A three-stage experimental constructed wetland for treatment of domestic sewage: First 2 years of operation, Ecological Engineering **37** (1) (2011) 90-98.
5. Abou-Elela S. I. and Hellal M. S. - Water. Municipal wastewater treatment using vertical flow constructed wetlands planted with *Canna, Phragmites* and *Cyprus*, Ecological Engineering **47** (2012) 209–213.
6. Barco A., and Borin M. - Treatment performance and macrophytes growth in a restored hybrid constructed wetland for municipal wastewater treatment, Ecological Engineering **107** (2017) 160-171.
7. García-Ávila F., Patiño-Chávez J., Zhinín-Chimbo F., Donoso-Moscoso S., Flores del Pino L. and Avilés-Añazco A. - Performance of *Phragmites australis* and *Cyperus papyrus* in the treatment of municipal wastewater by vertical flow subsurface constructed wetlands, International Soil and Water Conservation Research (2019)
   doi: https://doi.org/10.1016/j.iswcr.2019.04.001.
8. Andreo-Martínez P., García-Martínez N., Quesada-Medina J. and Almela L. - Domestic wastewaters reuse reclaimed by an improved horizontal subsurface-flow constructed wetland: A case study in the southeast of Spain, Bioresource Technology **233** (2017) 236-246.
9. Borin M., Politeo M. and Stefani G.D. - Performance of a hybrid constructed wetland treating piggery wastewater. Ecological Engineering **51** (2013) 229-236.
10. Meers E., Tack F.M.G., Tolpe I., and Michels E. - Application of a Full-scale Constructed Wetland for Tertiary Treatment of Piggery Manure: Monitoring Results, Water, Air, and Soil Pollution **193** (1) (2008) 15-24.
11. Luo P., Liu F., Zhang S., Li H., Chen X., Wu L., Jiang Q., Xiao R., and Wu J. - Evaluating organics removal performance from lagoon-pretreated swine wastewater in pilot-scale three-stage surface flow constructed wetlands, Chemosphere **211** (2018) 286-293.
12. González F.T, Vallejos G. G., Silveira J. H., Franco C. Q., García J. and Puigagut J. - Treatment of swine wastewater with subsurface-flow constructed wetlands in Yucatán, Mexico: Influence of plant species and contact time, Water SA **35** (3) (2009) 335-342.
13. Sezerino P. H., Reginatto V., Santos M. A., Kayser K., Kunst S., Philippi L. S., and Soares H. M. - Nutrient removal from piggery effluent using vertical flow constructed wetlands in southern Brazil, Water Science & Technology **48** (2) (2003) 129-35.
14. Kadlec R. H. - Comparison of free water and horizontal subsurface treatment wetlands, Ecological engineering **35** (2009) 159-174.
15. Naz M., Uyanik S., Yesilnacar M. I. and Sahinkaya E. - Side-by-side comparison of horizontal subsurface flow and free water surface flow constructed wetlands and artificial neural network (ANN) modelling approach, Ecological Engineering **35** (2009) 1255-1263.
16. Anh B. T. K, Kim D. D., Kuschk P., Tua T. V., Hue N. T., and Minh N. N. - Effect of soil pH on arsenic hyperaccumulation capacity in *Pityrogramma calomelanos* L., Journal of Environmental Biology **34** (2013) 237-242.
17. Mayes W. M., Batty L. C., Younger P. L., and Mander M. U. - Wetland Treatment at Extremes of Ph: A Review, Science of The Total Environment **407** (13) (2008) 3944-3957.
18. Vymazal J. - The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience, Ecological Engineering **18** (2002) 633-646.

19. Vymazal J., Brix H., and Cooper P. F. - Removal Mechanisms and Types of Constructed Wetlands, Leiden: Backhuys Publishers **1** (35) (1998) 4143.
20. Puigagut J., Vilaseňor J., Salas J. J., Béceras E., and García J. - Subsurface-flow constructed wetlands in Spain for the sanitation of small communities: a comparative study, Ecol Eng. **30** (2007) 312-9.
21. Klomjek P. - Swine wastewater treatment using vertical subsurface flow constructed wetland planted with Napier grass, Sustainable Environment Research, 2016. doi: 10.1016/j.serj.2016.03.001.
22. Vymazal J. - Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment, Ecological Engineering **25** (2005) 478-490.
23. Vymazal J. - Removal of nutrients in various types of constructed wetlands. Science of the Total Environment **380** (2007) 48-65.
24. Steer D. L, Frazer L. H., and Seibert B. A. - Cell to cell production reduction effectiveness of subsurface domestic treatment wetlands, Bioresour Tech. **96** (2005) 969-76.
25. Lee C. Y., Lee C. C., Lee F. Y., Tseng S. K., and Liao C. J. - Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads, Bioresour. Technol. **92** (2014) 173-179.
26. Mora-Orozco C. D. L., González-Acuña I. J., Saucedo-Terán R. A., Flores-López H. E., Rubio-Arias H. O. and Ochoa-Rivero J. M. - Removing Organic Matter and Nutrients from Pig Farm Wastewater with a Constructed Wetland System, Int J. Environ Res. Public Health **15** (5) (2018) 1031.
27. Liang Y. P., Ge Y., Yue C. L. and Chang J. - Nutrient Removal Role of Plants In Constructed Wetland on Sightseeing Water, Acta Ecologica Sinica **2** (8) (2004) 1718-1723.
28. Findlay S., Peter Groffman P. and Dye S. - Effects of *Phragmites australis* removal on marsh nutrient cycling, Wetlands Ecology and Management **11** (2003) 157-165.
29. Liu X., Zhang Y., Li X., Fu C., Shi T. and Yan P. - Effects of influent nitrogen loads on nitrogen and COD removal in horizontal subsurface flow constructed wetlands during different growth periods of *Phragmites australis*, Science of the Total Environment **635** (2018) 1360-1366.
30. Toet S., Bouwman M., Cevaal A., and Verhoeven J. T. - Nutrient removal through autumn harvest of *Phragmites australis* and *Thypha latifolia* shoots in relation to nutrient loading in a wetland system used for polishing sewage treatment plant effluent, J. Environ SciHealth A Tox Hazard Subst Environ Eng*,* **40** (6-7) (2005) 1133-56.
31. Kadlec R. H. and Wallace S. D. - Treatment wetlands second edition, Taylor & Francis Grou, 2009.
32. Stefanakis A. I., Akratos C. S., and Tsihrintzis V. A. - Vertical Flow Constructed Wetlands: Ecoengineering Systems for Wastewater and Sludge Treatment (1st ed.), Amsterdam, The Netherlands: Elsevier Publishing, 2014.